Chapter 6

Management Options for Animal Production Systems: Which Ones to Choose in the Event of a Nuclear or Radiological Emergency?

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6.1 Introduction

If radionuclides are released into a rural area as a result of a NRE, precautionary advice, including food restrictions, will be issued for places where permitted levels of radioactivity in food may be exceeded. The aim is to minimize the risk of people consuming contaminated food. Within few days, preliminary monitoring data may be available to help inform decisions on whether statutory food restrictions are required. These restrictions identify specific areas where activity concentrations of one or more radionuclides exceed OILs in foodstuffs. The areas subject to food restrictions may be large, and for some long-lived radionuclides, there is potential for a wide range of food production systems to be disrupted for many years, unless some form of intervention is undertaken. The implementation of management options is one form of protective action that will reduce the activity concentrations of radionuclides in foodstuffs to below OILs, thereby providing reassurance to consumers and sustaining production and livelihoods.

6.2 Management Options

Actions intended to reduce or avert radioactive contamination of agricultural products before they reach consumers have previously been referred to as agricultural countermeasures (IAEA 1994). The term ‘countermeasure’, although widely encountered, is often perceived by stakeholders as being a rather negative action (Nisbet et al. 2005). The term ‘management option’ has therefore tended to be used

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in recent years to encompass interventions aimed at reducing or averting contamination, or the likelihood of contamination, of food production systems. They are applied across all phases of the emergency timeline.

A large number of management options for use in intensive livestock production, backyard farms and free-ranging animals have been developed since the NRE at the Chernobyl NPP. Some of these options have been adapted and improved for site-specific conditions following the NRE at the Fukushima Daiichi NPP (NEA 2018). To capture relevant information about these management options and record it systematically, a datasheet template was designed (Nisbet et al. 2015). It takes into account criteria that decision-makers might wish to consider when evaluating different management options. A shortened version of the template has been used for the purposes of this book to provide some generic information on the management options that are applicable to animal production systems. This datasheet template can be found in Annex A, Table A1.

Management options can be implemented at different phases following the NRE, from pre-deposition (when there is a threat of release), through the urgent and early phase and into the late phase. Furthermore, the options can be targeted at specific radionuclides or particular contamination pathways, for example, the transfer from pasture to milk and meat, and during the processing of animal products.

Pre-deposition options, as their name suggests, are actions that need to be implemented prior to the deposition. They prevent radionuclides reaching food products by, for example, the closing of air intake systems at food processing plants, the covering of harvested fodder crops and the sheltering of livestock. These options are radionuclide-independent.

Other management options are implemented when the release of radionuclides to the environment has stopped. These options work by either targeting the live animal or one or more animal-derived food products. Options directed at live animals fall into two main categories: those that involve a change in husbandry practice (e.g. provision of uncontaminated feed) and are radionuclide-independent and those that require the use of additives to prevent or reduce the uptake of specific radionuclides into animals (e.g. Prussian blue to reduce gut uptake of radiocaesium). Live monitoring is useful in providing reassurance to consumers that contaminated produce is not entering the food chain. In situations where it is not possible to adequately reduce concentrations of radionuclides in live animals, slaughter (also known as culling) followed by disposal must be considered as a last-resort option. To reduce the quantities of waste, processing of contaminated animal products followed by storage (e.g. salting of meat, and cheese or butter production) can be effective at reducing radionuclides to levels below the OILs.

Many management options are of a technical nature involving some form of physical or chemical intervention to reduce transfer of radionuclides in the food chain. Other management options can be considered to have more societal relevance. These include support for self-help measures by local provision of monitoring equipment and the raising of intervention levels for animal products to maintain traditional farming practices and ways of life.

The placing of statutory restrictions on the marketing of animal products can generate considerable volumes of contaminated biodegradable waste. Appropriate

routes of disposal need to be identified, ideally in advance of a NRE. There are many types of disposal routes that can be considered, ranging from relatively simple in situ methods (e.g. landspreading of milk) to offsite commercial treatment facilities (e.g. incineration of animal carcasses).

Table 6.1 provides an alphabetical list of all the management options considered in this chapter. A distinction is made between options directed at live animals and options directed at animal products. There is also an additional category listing options for disposing of waste produce. Datasheets for these management options

Table 6.1 Management options for animal production systems

Category	Subcategory	No.	Management option
Applicable to live animals (15 management options)	Change husbandry practices (10 options)	1	Clean feeding
		2	Live monitoring
		3	Manipulation of slaughter times
		4	Natural attenuation with monitoring
		5	Restrictions on hunting
		6	Select alternative land use
		7	Selective grazing regime
		8	Short-term sheltering of dairy animals
		9	Slaughtering (culling) of livestock
		10	Suppression of lactation before slaughter
	Use of additives (5 options)	11	Addition of AF ^a CF to feed
		12	Addition of calcium to feed
		13	Addition of clay minerals to feed
		14	Administration of AF ^a CF boli to ruminants
		15	Distribution of saltlicks containing AF ^a CF
Applicable to animal products (9 management options)		16	Closure of air intake systems at processing plants
		17	Decontamination of milk
		18	Dilution
		19	Local provision of monitoring equipment
		20	Processing of milk for consumption
		21	Product recall
		22	Raise intervention levels
		23	Restrict entry of food into food chain
		24	Salting of meat
Applicable to waste disposal (9 management options)		25	Biological treatment of milk
		26	Burial of animal carcasses
		27	Burning of animal carcasses
		28	Disposal of milk to sea
		29	Incineration
		30	Landfill
		31	Landspreading
		32	Processing and long-term storage
		33	Rendering

^aAF^aCF is also known as Prussian blue

can be found in Annex A, based on published information for the UK (Nisbet et al. 2015) and Europe (Nisbet et al. 2009). The datasheets have been shortened and adapted where relevant to backyard production.

6.3 Radionuclides of Importance

During an NRE a mix of radionuclides will be released. The mix depends on both the type of source and the nature of the NRE. However, generally, ^{134}Cs , ^{137}Cs and ^{131}I are of particular interest because of their likelihood of release and subsequent impact on people. This can be due to external exposure from inhabited surfaces (which is dominated by caesium isotopes) or ingestion of contaminated food products (where exposure is dominated by caesium and iodine isotopes). In food production systems, radioiodine tends to cause severe short-term problems, whilst radiocaesium has a longer-term impact. Both radionuclides had a significant radiological impact following the NPP NREs at Chernobyl and Fukushima Daiichi. There are other types of NREs (e.g. transport accidents and fires at sites holding radioactive materials) that have the potential to release a wider range of radionuclides into the environment. The most important radionuclides considered to pose a threat to food production systems are ^{89}Sr , ^{90}Sr , ^{131}I , ^{134}Cs , ^{137}Cs , ^{238}Pu and ^{241}Am .

6.4 Seasonality and Radioecological Zoning

The seasons of the year when deposition occurs can have a significant influence on contamination levels in animals and animal products and hence the management strategy adopted. This is particularly the case for MS that house livestock for part or all of the year and provide stored feed. This can lead to seasonal variations in radionuclide concentrations in milk and meat (by up to three orders of magnitude) according to the timing of when (or if) animals are fed contaminated feed or return to contaminated pasture with respect to timing of deposition.

6.5 Decision-Aiding Handbooks for Food Production Systems

In advance of a NRE, decision-makers will need to be in a position to construct a strategy for managing contaminated animal production systems. For small-scale, single radionuclide releases, the strategy may comprise one or two management options that could be applied over the first few days or weeks following the NRE. For wide-scale releases of multiple radionuclides, a management strategy is likely to be more complex, comprising a series of management options that could be

implemented over different phases of emergency response and affecting several types of production system.

The selection of individual options depends on a wide range of criteria including effectiveness, technical feasibility, impact (e.g. agricultural, environmental and societal) and cost. For any one NRE scenario, only a subset of options will be applicable. However, as each NRE will be different in terms of its radiological composition and impact on the food chain, it is not possible to establish a generic strategy. Consequently, handbooks for food production systems (as well as inhabited areas and drinking water supplies) were developed in close collaboration with stakeholders to aid decision-makers in the selection and combining of management options in the UK (Nisbet et al. 2015) and Europe (Nisbet et al. 2009). The handbooks can be used in emergency response, or as a preparatory tool, under noncrisis conditions, to engage stakeholders and to develop local and regional plans. In addition, the handbooks are useful for training purposes and for application during emergency exercises.

The handbook for food production systems contains an eight-step decision-aiding framework. This comprises various look-up tables aimed at helping those developing the recovery strategy to progressively evaluate the options and eliminate those deemed unsuitable. This informs the decision-making process and provides a short list of options. The datasheets can then be used to provide important supporting information on, for example, effectiveness, feasibility, waste generation and cost.

6.5.1 Decision-Aiding Framework

The eight-step decision-aiding process to support the management of contaminated animal production systems is summarized below.

Step	Action
1	Identify one or more production systems that are likely to be/have been contaminated
2	Refer to selection tables for either milk or meat production systems. These selection tables provide a list of relevant management options, including those for waste disposal
3	Refer to look-up tables showing applicability of management options for each radionuclide
4	Refer to look-up tables showing key constraints for each management option
5	Refer to look-up table showing typical effectiveness of each management option
6	Refer to look-up table showing whether options incur additional doses to those involved in their implementation either directly or through the management of any secondary wastes
7	Refer to individual datasheets for remaining options and note any additional constraints
8	Based on the outputs from Steps 1 to 7, select and combine options that should be considered as part of the recovery strategy

Further guidance on each of the steps is provided in the following subsections.

6.5.2 Selection Tables (Step 2)

Color-coded selection tables are presented for milk (Table 6.2) and meat (Table 6.3). These selection tables provide:

- A list of all of the relevant management options for the production system selected, including those for disposal of any waste arisings
- An indication of whether the management options are suitable for implementation in the pre-deposition, urgent, early or late phases
- A color-coded guide to indicate how easy it is likely to be, to implement the management options based on general knowledge of potential technical, logistical, economic or social constraints. The color-coding distinguishes between:

Table 6.2 Selection table of management options for maintaining production of milk

	Pre-deposition	Urgent phase	Early phase	Late phase
Live animals				
Change in husbandry practice				
Clean feeding				
Natural attenuation & monitoring				
Selective grazing				
Select alternative land use				
Short-term sheltering of animals				
Slaughtering (culling) of livestock				
Suppress lactation before slaughter				
Use of additives				
Addition of AFCF to feed				
Addition of calcium to feed				
Addition of clay minerals to feed				
Administer AFCF boli to ruminants				
Distribution of AFCF saltlicks				
Animal products				
Close air intake at processing plants				
Decontamination of milk				
Dilution				
Provision of monitoring equipment				
Processing of milk for consumption				
Product recall				
Raise intervention levels				
Restrict entry to foodchain				
Waste disposal				
Biological treatment of milk				
Disposal to sea				
Incineration				
Landspreading				
Processing & long-term storage				
	Recommended with few constraints.			
	Recommended but requires further analysis to overcome some constraints.			
	Economic or social constraints; requires full analysis and consultation.			
	Technical or logistical constraints; may only be appropriate on a site-specific basis.			
	Requires full analysis and consultation.			

Table 6.3 Selection table of management options for maintaining production of meat

Management options	Pre-deposition	Urgent phase	Early phase	Late phase
Live animals				
Change in husbandry practice				
Change hunting season				
Clean feeding				
Live monitoring				
Natural attenuation & monitoring				
Manipulate slaughter times				
Select alternative land use				
Selective grazing				
Slaughtering (culling) of livestock				
Use of additives				
Addition of AFCF to feed				
Addition of calcium to feed				
Addition of clay minerals to feed				
Administer AFCF boli to ruminants				
Distribution of AFCF saltlicks				
Animal products				
Close air intake at processing plants				
Provision of monitoring equipment				
Product recall				
Raise intervention levels				
Restrict entry to foodchain				
Salting of meat				
Waste disposal				
Burial of carcasses				
Burning of carcasses				
Incineration				
Landfill				
Rendering				
	Recommended with few constraints.			
	Recommended but requires further analysis to overcome some constraints.			
	Economic or social constraints; requires full analysis and consultation.			
	Technical or logistical constraints; may, or only be appropriate on a site-specific basis. Requires full analysis and consultation.			

- Options that would usually be justified or recommended having few if any constraints (green)
- Options that would also be recommended but would require further analysis to overcome potentially serious constraints (yellow)
- Options that would have to undergo a full analysis and consultation with stakeholders before implementation because of serious economic or social constraints (pink)
- Options that would only be justified in specific circumstances following full analysis and consultation due to major technical or logistical constraints (red)

The classification used in the selection tables is intended to be a guide and requires customization at local or regional level by the relevant stakeholders.

So, for milk, the optimum strategy might be as follows:

	Pre-deposition	Urgent phase	Early phase	Late phase
Live animals	Short-term sheltering	Clean feeding ^a	Clean feeding ^a Feed additives Selective grazing	Feed additives Selective grazing
Animal products	n/a	Restrict entry Product recall	Restrict entry	Restrict entry
Waste disposal	n/a	Landspreading	Landspreading	Landspreading

^aClean feeding involves the provision of uncontaminated or less contaminated feed

6.5.3 *Applicability of Management Options for Different Radionuclides (Step 3)*

Most of the information that is available on management options relates to radioactive isotopes of iodine and caesium due to the importance of their radiological impact in previous NREs. For the other radionuclides considered, there are few data to indicate whether a particular management option is applicable or not. Nevertheless, these radionuclides have certain characteristics in terms of their physical half-life, chemical form, mobility in soil and photon energy as well as other characteristics that will give a guide as to whether an option should be considered or eliminated.

Table 6.4 indicates whether a management option is likely to be applicable or not according to radionuclide. An option is considered to be applicable if:

- There is direct evidence that it is effective for a radionuclide (known applicability).
- The mechanism of action is such that it would be highly likely to be effective for a radionuclide, e.g. on the basis of similar chemical, biological or physical characteristics (probably applicable).

The category of 'not applicable' is attributed to an option if:

- There is direct evidence that it is not effective for the radionuclide.
- There is insufficient evidence on the option-radionuclide combination to make a judgement on effectiveness.
- The physical half-life of the radionuclide. Some management options take a long time to organize and implement so may not be appropriate for radionuclides with short half-lives.
- The low environmental mobility or biological uptake of a radionuclide does not justify the degree of disruption that may be caused by some of the more radical options (e.g. select alternative land use, slaughtering of dairy livestock).

Table 6.4 Applicability of management options for different radionuclides

Management options	Radionuclides						
	⁸⁹ Sr	⁹⁰ Sr	¹³¹ I	¹³⁴ Cs	¹³⁷ Cs	²³⁸ Pu	²⁴¹ Am
Radionuclide half-life	50.5 d	29.12 y	8.04 d	2.062 y	30.17 y	87.74 y	432.2 y
Live animals							
<u>Change in husbandry practice</u>							
Change hunting season	✓	✓	✓	✓	✓	✓	✓
Clean feeding	✓	✓	✓	✓	✓	✓	✓
Live monitoring	d	d	✓	✓	✓	d	d
Manipulate slaughter time	✓	✓	✓	✓	✓	✓	✓
Natural attenuation (with monitoring)	d	d	✓	✓	✓	d, g	d, g
Select alternative land use	c	✓	c	✓	✓	e, f	e, f
Selective grazing	✓	✓	c	✓	✓	e	e
Short-term sheltering of animals	✓	✓	✓	✓	✓	✓	✓
Slaughtering (culling) of livestock	✓	✓	c	✓	✓	e	e
Suppression of lactation before slaughter	✓	✓	c	✓	✓	e	e
<u>Use of additives</u>							
Addition of AFCF to feed	a	a	a	✓	✓	a	a
Addition of calcium to feed	✓	✓	b	b	b	b	b
Addition of clay minerals to feed	a	a	a	✓	✓	a	a
Administer AFCF boli to ruminants	a	a	a	✓	✓	a	a
Distribution of AFCF saltlicks	a	a	a	✓	✓	a	a
<u>Animal products</u>							
Close air intake at food processing plants	✓	✓	✓	✓	✓	✓	✓
Decontamination of milk	✓	✓	c	✓	✓	a	a
Dilution	✓	✓	✓	✓	✓	✓	✓
Provision of monitoring equipment	d	d	✓	✓	✓	d	✓
Processing of milk for consumption	✓	✓	✓	✓	g	g	g
Product recall	✓	✓	✓	✓	✓	✓	✓
Raise intervention levels	✓	✓	✓	✓	✓	✓	✓
Restrict entry into the food chain	✓	✓	✓	✓	✓	✓	✓
Salting of meat	a	a	a	✓	✓	a	a

Key:

Half-life: d = days, y = years

✓: Selected as target radionuclide (i.e. known or probable applicability)

a: Management option specific for Cs

b: Management option specific for radionuclides in Group II of periodic table

c: Comparatively short physical half-life of radionuclide relative to timescale of implementation of the management option

d: No/low photon energy of radionuclide makes detection difficult

e: Radionuclide has low feed-to-meat or milk transfer, making radical management options inappropriate

f: Low soil-to-plant transfer makes radical management option inappropriate

g: Management option only effective for short-lived radionuclides

Table 6.5 indicates whether a waste disposal option is likely to be applicable or not according to radionuclide. Five criteria were used to assess applicability:

- Volatilization temperature of the radionuclide. This affects options which are carried out at higher than ambient temperature (burning and incineration).
- Mobility of the radionuclide in soil. This relates to options where the waste may come into contact with soil at depth (burial, landfill).
- Physical half-life of the radionuclide. This affects options with relatively long implementation times.
- Uptake of the radionuclide by marine biota (disposal of milk to sea).

Table 6.5 Applicability of waste disposal options for different radionuclides

Management options	Radionuclides						
	⁸⁹ Sr	⁹⁰ Sr	¹³¹ I	¹³⁴ Cs	¹³⁷ Cs	²³⁸ Pu	²⁴¹ Am
Radionuclide half-life	50.5 d	29.12 y	8.04 d	2.062 y	30.17 y	87.74 y	432.2 y
Biological treatment (digestion) of milk [#]	✓	✓	✓	✓	✓	✓	✓
Burial of carcasses [†]	a	a	a	✓	✓	✓	✓
Burning of carcasses	✓	✓	d, b	d	d	✓	✓
Disposal of contaminated milk to sea	✓	✓	✓	✓	✓	c	c
Incineration [‡] (1100 °C) [‡]	✓	✓	d, b	d	d	✓	✓
Landfill [†]	a	a	a, b	✓	✓	✓	✓
Landspreading of milk and/or slurry [#]	✓	✓	✓	✓	✓	✓	✓
Processing and storage of milk for disposal	✓	✓	✓	✓	✓	✓	✓
Rendering [‡] (150 °C) [‡]	✓	✓	b	✓	✓	✓	✓

Key:

Half-life: d = days, y = years

✓: Selected as target radionuclide (i.e. known or probable applicability)

a: Not recommended due to the potential rapid movement of the radionuclide in the ground after burial, taken to be represented by a soil mobility (K_d) of between 0 and 30

b: Not recommended due to comparatively short physical half-life of radionuclide relative to timescale of implementation of the management option

c: Not recommended due to the potential for the radionuclide to concentrate in marine foods, taken to be represented by a concentration ratio in marine foods (fish, crustaceans and molluscs) of 1000 or more

d: Not recommended as boiling temperature is below temperature of option. Volatilization may occur

[#]: Nuclides placed or deposited onto surface layers of soil – only plant uptake is considered

[†]: Nuclides are considered to be buried under clean soil – only mobility is considered

[‡]: Maximum temperature at which option is carried out. Operating temperature is typically 850–1100 °C and usually 900 °C

[‡]: Maximum temperature at which option is carried out, typically between 100 and 145 °C

6.5.4 Key Constraints Affecting Management Options (Step 4)

Management options invariably have some constraints associated with their implementation. To assist in eliminating unsuitable options, major constraints for each option are presented in Table 6.6 taking into account technical feasibility and capacity, timescales for implementation, waste generation and societal needs. If a major constraint is identified, it does not necessarily indicate that the management option should be eliminated but does raise awareness of specific issues that need to be overcome.

Table 6.6 Key constraints for each management option

Management option	Major (key) constraints
Live animals	
<u>Change in husbandry practice</u>	
Change hunting season	Challenges with enforceability and policing
Clean feeding	Availability of suitable housing with water, power supply, straw for bedding and ventilation Availability of alternative clean feed
Live monitoring	Availability of NaI detectors and trained personnel
Manipulate slaughter time	Availability of abattoir or on-farm slaughtering equipment if immediate slaughter is agreed Availability of additional feed and any implications for animal welfare if prolonged slaughter is agreed
Natural attenuation (with monitoring)	It may take a prolonged period of time for the radionuclides to undergo radioactive decay and weathering from land surfaces Availability of monitoring equipment and skilled personnel to take measurements and samples
Select alternative land use	Market for alternative products and know-how
Selective grazing	Availability of less contaminated land in the area
Short-term sheltering of animals	Time between notification and radionuclide release Availability of suitable housing with water supply
Slaughtering (culling) of livestock	Availability of slaughtering equipment and licensed slaughter men Availability of rendering, incineration and landfill facilities for livestock carcasses if large numbers of animals are culled Disruption to and impact on farmers and food industry Resistance from farmers and members of the public
Suppression of lactation before slaughter	None
<u>Use of additives</u>	
Addition of AFCF to feed	Availability of AFCF and identification of feed manufacturing plants that will add AFCF to feed pellets
Addition of calcium to feed	None
Addition of clay minerals to feed	Availability of clay minerals and identification of feed manufacturing plants that will add clay minerals to feed pellets (clay mineral needs to be compliant with animal feed legislation)

(continued)

Table 6.6 (continued)

Management option	Major (key) constraints
Administration of AFCF boli to ruminants	Availability of AFCF and identification of manufacturing plants that will can produce AFCF boli
Distribution of AFCF saltlicks	Not in coastal areas, only where animals are salt-deficient
Animal products	
Close air intake at food processing plants	Time between notification and radionuclide release
Decontamination of milk	Loss of confidence in the food chain May affect nutritional quality of milk
Dilution	May generate mistrust in the food chain and undermine consumer confidence
Provision of monitoring equipment	Availability of NaI detectors and trained personnel; time will be required to manufacture and calibrate monitoring kits and train personnel
Processing or milk for consumption	May generate mistrust in the food chain and undermine consumer confidence
Product recall	Availability of tracking systems to identify potentially contaminated products that may be in the food chain
Raise intervention levels	Loss of confidence in the food chain
Restrict entry into the food chain	Availability of disposal routes for contaminated food products
Salting of meat	May generate mistrust in the food chain and undermine consumer confidence
Waste disposal options	
Biological treatment (digestion) of milk	Capacity of biological treatment facilities for milk which has a very high biological oxygen demand
Burial of carcasses	Availability and suitability of land for engineering a purpose built burial pit Selection of burial site
Burning of carcasses	Availability of suitable sites due to potential for air and water pollution
Disposal of contaminated milk to sea	Identification of long sea outfalls with the capacity to discharge milk, authorization to discharge milk to sea and transportation and offloading at discharge points
Incineration	Availability of commercial facilities able to accept contaminated material and capacity in the area
Landfill	Availability and capacity of commercial facilities for highly biodegradable material
Landspreading of milk and/or slurry	Availability of land for landspreading (not waterlogged, frozen, in nitrate sensitive area) Capacity of slurry tank to store milk at times when land not suitable for spreading
Processing and storage of milk for disposal	Availability of processing plant willing to accept contaminated milk Availability of storage facility
Rendering	Availability of commercial facilities and capacity in the area

6.5.4.1 Technical Feasibility and Capacity

An option is considered to be technically feasible if the equipment, techniques and resources required to implement it are available in the affected area or can be obtained from outside the area in sufficient number. The capacity of or scale on which an option can be implemented is determined by available manpower, work rates for equipment and restrictions in minimum or maximum areas of land or volumes of material that can be treated.

6.5.4.2 Timescales for Implementation

Selection of management options should take into account time-related aspects (e.g. when the NRE happened, the elapsed time, temporal variation in activity concentrations of radionuclides in the environment and their movement through the food chain). In the case of rapidly developing NREs, alerts are only given after the release has started. If the alert comes too late, it will not be possible to implement pre-deposition options such as the sheltering of dairy animals. For some options, the time of year that the NRE takes place can affect applicability, for example, clean feeding is constrained by the availability of stored clean feed, which tends to be lowest at the start of the growing season. Other options such as incorporation of dietary additives into animal feed or boli take time to organize and prepare, so would not necessarily be available in the urgent phase.

6.5.4.3 Waste Generation

It is not just the placing of restrictions on foodstuffs or product recall that creates wastes. Several management options also produce contaminated by-products (e.g. slaughtering of dairy cows, processing of milk and meat), and routes for their disposal must be considered at the point at which the option is selected. The following criteria are important when selecting disposal routes:

- Characteristics of the waste (volume and activity)
- Legislation concerning disposal routes for the waste
- Capacity of disposal facilities
- Impact of disposal on agricultural land and the environment
- Doses to those handling the waste

Disposal routes for contaminated milk include landspreading, anaerobic digestion, discharge through long sea outfalls and incineration. Options for animal carcasses and meat include burial, burning, incineration and landfill.

6.5.4.4 Environmental Impact

Management options can have positive or negative and direct or indirect impacts on the environment. Direct environmental impacts can include changes in biodiversity from changes in grazing pressure brought about by selective grazing and manipulation of slaughtering times. Pollution of watercourses can occur due to inappropriate landspreading of milk. Indirect effects on the environment can happen, for example, when an individual freedom's is reduced by changes to traditional lifestyles, e.g. restrictions on hunting.

6.5.4.5 Cost

It is very difficult to predict the economic cost of implementing management options because of the numerous factors that influence cost. There are direct costs, such as costs linked to lost production, costs from the implementation of options (labour, equipment, consumables, transport, etc.) and costs from the handling of wastes. Indirect costs include those incurred through the impact on the environment and tourism and loss of market share. The magnitude of these direct and indirect costs will depend on many factors such as the time of year of the NRE. NREs occurring at the start of the growing season have larger consequences for food production systems than those occurring after harvest. Also, relevant is the period of time over which a management option is implemented and the scale of the NRE, as costs are proportional to the area of land affected and the type of land use. Costs for remediating intensive agricultural production are likely to be higher than for small-scale production systems.

6.5.5 Effectiveness of Management Options (Step 5)

The primary aim of many of the management options considered for food production systems is to reduce doses from the consumption of contaminated foodstuffs. Options will be chosen if they reduce activity concentrations in milk and meat to below OILs. Effectiveness is influenced by both technical and societal criteria (e.g. application rates, duration of treatments, physical and chemical form of the radionuclide in the environment, biological half-life, timeliness of implementation and compliance in implementation). They will vary therefore according to the prevailing circumstances. Some management options are included as supporting measures (e.g. live monitoring) and do not reduce doses in their own right but provide valuable reassurance.

Experimental work and field-based studies in the regions affected by the NREs such as Chernobyl and Fukushima Daiichi have enabled the effectiveness of various management options to be assessed under field conditions. Effectiveness is generally expressed as percentage reduction in activity concentration in the target medium (food product) following implementation of a management option. Table 6.7 provides a look-up table on the typical effectiveness of management options for a range of radionuclides and animal products. More detailed information on effectiveness is provided in the datasheets (Annex A).

Table 6.7 Effectiveness of management options

Management option	Radionuclides	Effectiveness	Comments
Live animals			
<u>Change in husbandry</u>			
Change hunting season	^{134}Cs , ^{137}Cs	65–85%	Moose and reindeer
Clean feeding	All	Up to 100%	
Live monitoring	^{134}Cs , ^{137}Cs	Up to 100%	Does not remove the radionuclide but can be highly effective at excluding meat above intervention level from food chain
Manipulate slaughter time	^{134}Cs , ^{137}Cs	30–75%	Sheep and reindeer. Highly variable
Natural attenuation (with monitoring)	All	Not applicable	Does not remove the radionuclide. Decay will occur but may take a long time
Select alternative land use	All except ^{131}I	100%	Does not remove contamination but the ingestion pathway is no longer relevant since inedible crops have replaced crops grown for the food chain
Selective grazing	All	50–80%	Milk and meat
Short-term sheltering of animals	All	Up to 100%	Milk and meat
Slaughtering (culling) of livestock	^{89}Sr , ^{90}Sr , ^{134}Cs , ^{137}Cs	Up to 100%	Does not remove the radionuclide but can be highly effective at excluding foodstuffs above the intervention level from food chain
Suppression of lactation before slaughter	^{134}Cs , ^{137}Cs	Up to 100%	Can be considered as 100% effective if lactation is ceased
<u>Use of additives</u>			
Addition of AFCF to feed	^{134}Cs , ^{137}Cs	75–85%	Sheep, goats, cows and pigs
Addition of calcium to feed	^{89}Sr , ^{90}Sr	50%	Milk
Addition of clay minerals to feed	^{134}Cs , ^{137}Cs	50%	Beef

(continued)

Table 6.7 (continued)

Management option	Radionuclides	Effectiveness	Comments
Administration of AFCF boli to ruminants	^{134}Cs , ^{137}Cs	50–80%	Sheep, reindeer, goat and cow
Distribution of AFCF saltlicks	^{134}Cs , ^{137}Cs	50%	Highly variable within a herd or flock. Only effective if animals are salt-deficient
Animal products			
Close air intake at food processing plants	All	Up to 100%	
Decontamination of milk	^{89}Sr , ^{90}Sr , ^{134}Cs , ^{137}Cs	Up to 90%	Electrodialysis Ultrafiltration (Cs only) ~99%
Dilution	All	Not applicable	Does not reduce doses Very effective at reducing volumes of milk requiring disposal
Provision of monitoring equipment	^{134}Cs , ^{137}Cs	Up to 100%	
Processing of milk for consumption	^{89}Sr , ^{90}Sr , ^{134}Cs , ^{137}Cs ^{131}I	50% 80% 100%	Blanching Meat and fish in brine Storage (^{131}I only)
Product recall	All	Up to 100%	
Raise intervention levels	All	Not applicable	Will lead to increase in doses Very effective at reducing volumes of milk requiring disposal
Restrict entry into the food chain	All	Up to 100%	
Salting of meat	^{89}Sr , ^{90}Sr , ^{134}Cs , ^{137}Cs	Up to 80%	Depends on size of pieces of meat, duration of treatment, concentration of salt

6.5.6 Management Options Incurring an Additional Dose to Implementers (Step 6)

Although management options are chosen to reduce doses from ingestion of contaminated produce, additional doses can be received by those responsible for implementing the options, when they are not part of their routine work. These doses are most likely to be received by veterinarians, farmers and those working on the land. Some management options generate secondary wastes that require disposal (e.g. from food restrictions, food processing and the slaughtering of live-stock), which may result in workers at waste management facilities receiving additional doses. A number of factors influence the magnitude of the doses received: radionuclides present, exposure pathways and exposure time. In general, the additional doses received from implementation of management options are trivial. Waste disposal options that concentrate and contain radionuclides are those

most likely to incur the largest doses and for which a dose assessment should be carried out. Table 6.8 gives a list of management options for milk and meat, showing whether they result in an additional dose to implementers either directly or through the subsequent generation and management of secondary wastes. Table 6.9

Table 6.8 Management options incurring additional doses to implementers

Management option	Incremental dose from management option	Waste produced	Incremental dose from waste management
Live animals			
<u>Change in husbandry</u>			
Change hunting season	×	×	×
Clean feeding	✓	✓	✓
Live monitoring	✓	×	×
Manipulate slaughter time	✓	×	×
Natural attenuation (with monitoring)	✓	×	×
Select alternative land use	✓	×	×
Selective grazing	✓	×	×
Short-term sheltering of animals	×	×	×
Slaughtering (culling) of livestock	✓	✓	✓
Suppression of lactation before slaughter	×	×	×
<u>Use of additives</u>			
Addition of AFCF to feed	×	×	×
Addition of calcium to feed	×	×	×
Addition of clay minerals to feed	×	×	×
Administration of AFCF boli to ruminants	×	×	×
Distribution of AFCF saltlicks	×	×	×
<u>Animal products</u>			
Close air intake at food processing plants	×	×	×
Decontamination of milk	✓	✓	✓
Dilution	×	×	×
Provision of monitoring equipment	✓	×	×
Processing or storage of food products	✓	✓	✓
Product recall	×	✓	✓
Raise intervention levels	×	×	×
Restrict entry into the food chain	×	✓	✓
Salting of meat	✓	✓	✓

Table 6.9 Additional doses incurred following implementation of waste disposal options

Management option	Additional dose to implementers	Additional dose to the public	
		Primary waste	Secondary waste
Biological treatment (digestion) of milk	✓	×	✓
Burial of carcasses	✓	×	✓
Burning of carcasses	✓	×	✓
Disposal of contaminated milk to sea	✓	✓	×
Incineration	✓	×	×
Landfill	✓	×	✓
Landspreading of milk and/or slurry	✓	✓	×
Processing and storage of milk products for disposal	✓	×	×
Rendering	✓	×	×

gives a list of waste disposal options, showing whether they result in an additional dose to implementers and members of the public. This information will not necessarily eliminate options but serves to warn the decision-maker that selection of particular options will have implications for wastes and doses, some of which will require further assessment before implementation. It will be important to monitor all locations where disposal of contaminated animal products and carcasses has been carried out.

6.5.7 Consideration of the Datasheets (Step 7)

A subset of options remaining in the selection table after Step 6 are those most likely to be incorporated into the overall management strategy. A closer look at the datasheets contained in Annex A will confirm whether any additional constraints might preclude further options from being considered. This can only be done on a site and incident-specific basis, according to the prevailing circumstances and in conjunction with all of the relevant stakeholders.

6.5.8 Selecting and Combining Options to Develop the Management Strategy (Step 8)

The management strategy will consist of a number of management options that can be applied either singly or in combination during the pre-deposition phase and/or in the days, weeks, months and even years following the NRE. The strategy is not

fixed. It is regularly reviewed and updated according to the effectiveness of the measures, taking into account the views of all the relevant stakeholders. Several hypothetical worked examples have been developed to help illustrate how the decision-aiding framework can be used to select and combine options in the development of a management strategy. These worked examples are presented in Annex B.

References

- IAEA. (1994). *Guidelines for agricultural countermeasures following an accidental release of radionuclides* (Technical report series 363). Vienna: IAE Agency.
- NEA. (2018). *NEA international workshop on post-accident food safety science – Summary report*.
- Nisbet, A. F., Mercer, J. A., Rantavaara, A., Hanninen, R., Vandecasteele, C., Carlé, B., Hardeman, F., Ioannides, K., Papachristodoulou, C., Tziella, C., Ollagnon, H., Jullien, T., & Pupin, V. (2005). Achievements, difficulties and future challenges for the FARMING network. *Journal of Environmental Radioactivity*, 83, 263–274.
- Nisbet, A. F., Jones, A., Turcanu, C., Camps, J., Andersson, K. G., et al. (2009). *Generic handbooks for assisting in the management of contaminated food production systems in Europe following a radiological emergency*. EUR 24457 EN.
- Nisbet, A. F., Watson, S. J., & Brown, J. (2015). *UK recovery handbooks for radiation incidents 2015*. Chilton, PHE-CRCE-018. Available at: <https://www.gov.uk/government/publications/uk-recovery-handbooks-for-radiation-incidents-2015>

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